GENI Program Overview & Introductions

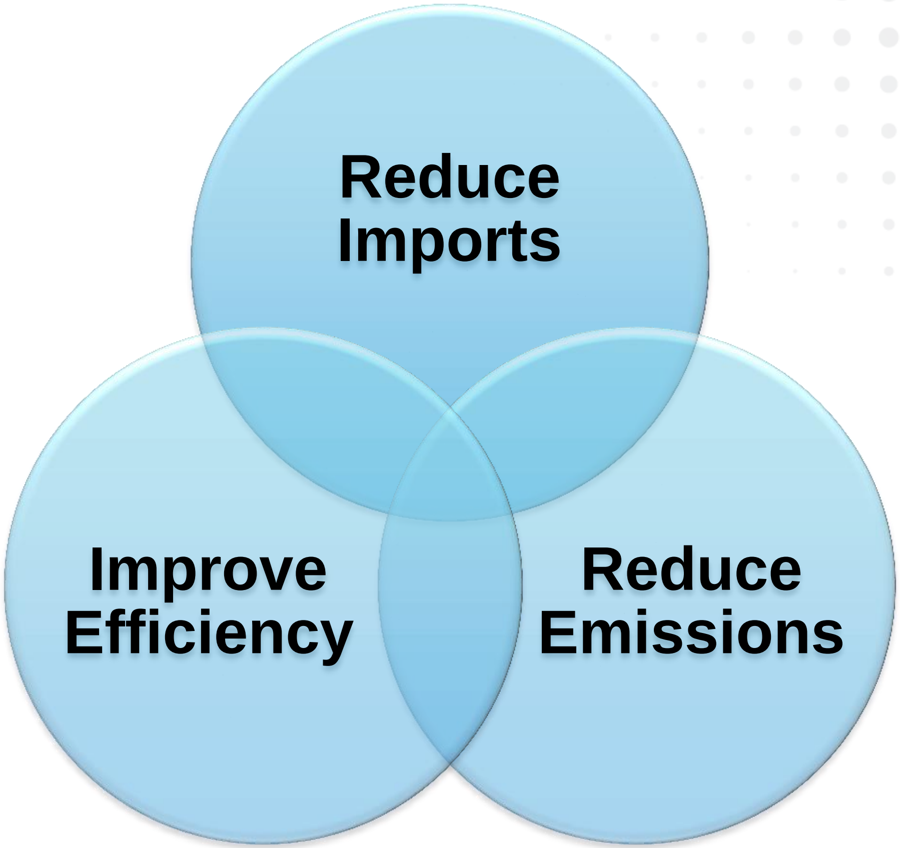
Tim Heidel
Program Director
Advanced Research Projects Agency – Energy (ARPA-E)
U.S. Department of Energy

GENI Annual Program Review
New Orleans, LA, January 14-15, 2015

The ARPA-E Mission

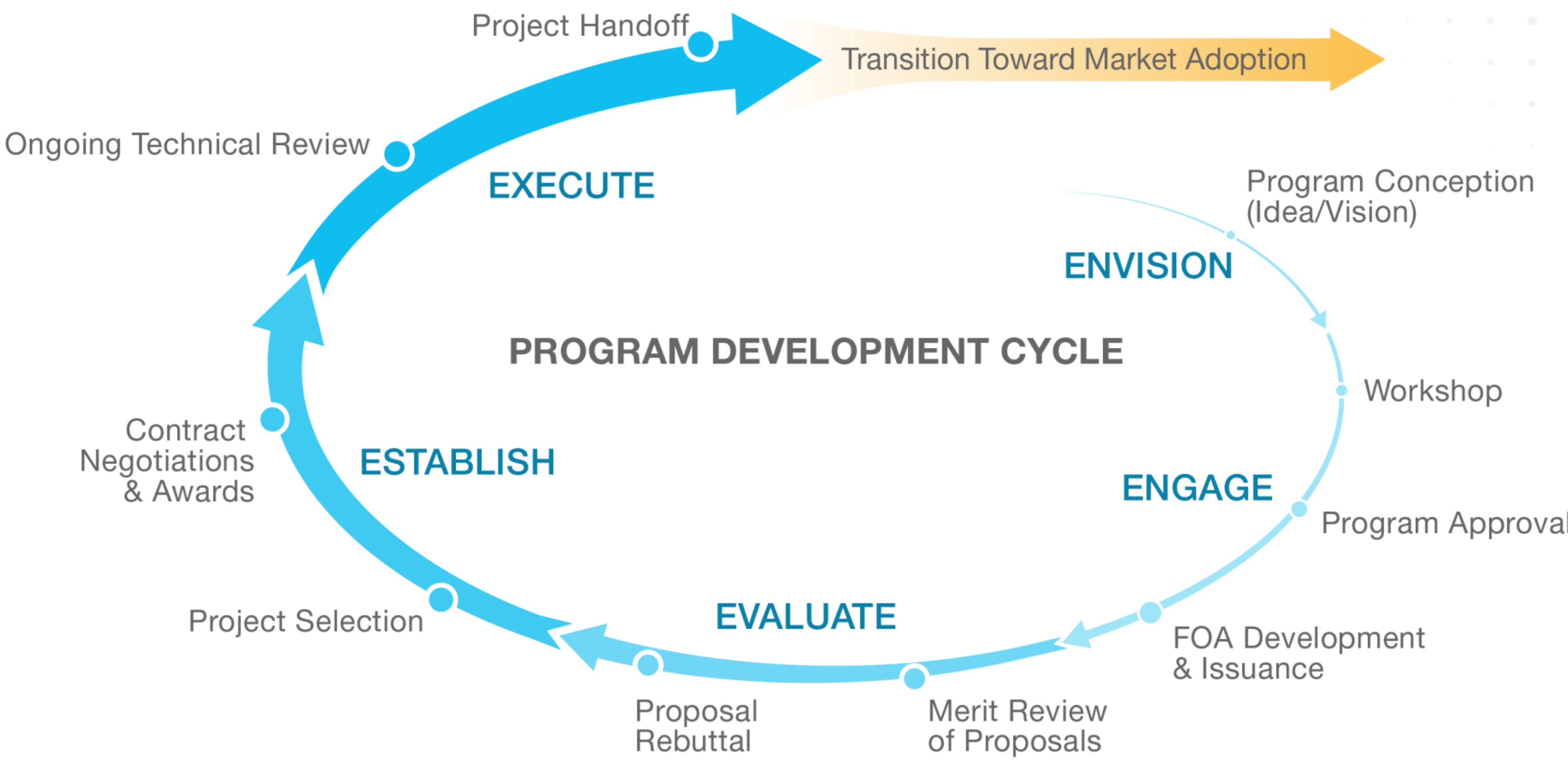
Ensure America's

- National Security
- Economic Security
- Energy Security
- Technological Competiveness



Catalyze and support the development of transformational, disruptive energy technologies

Technology Acceleration Model



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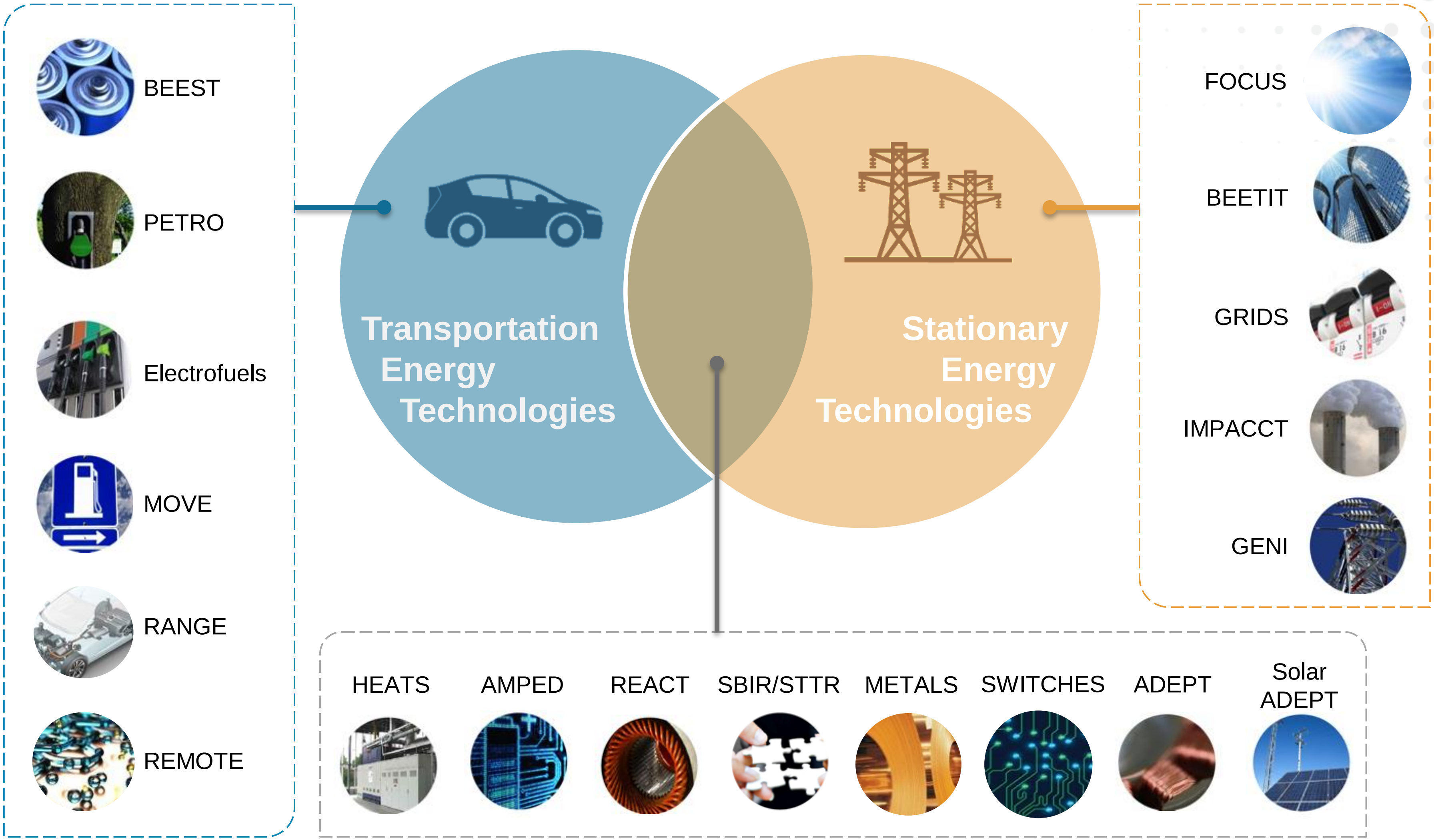
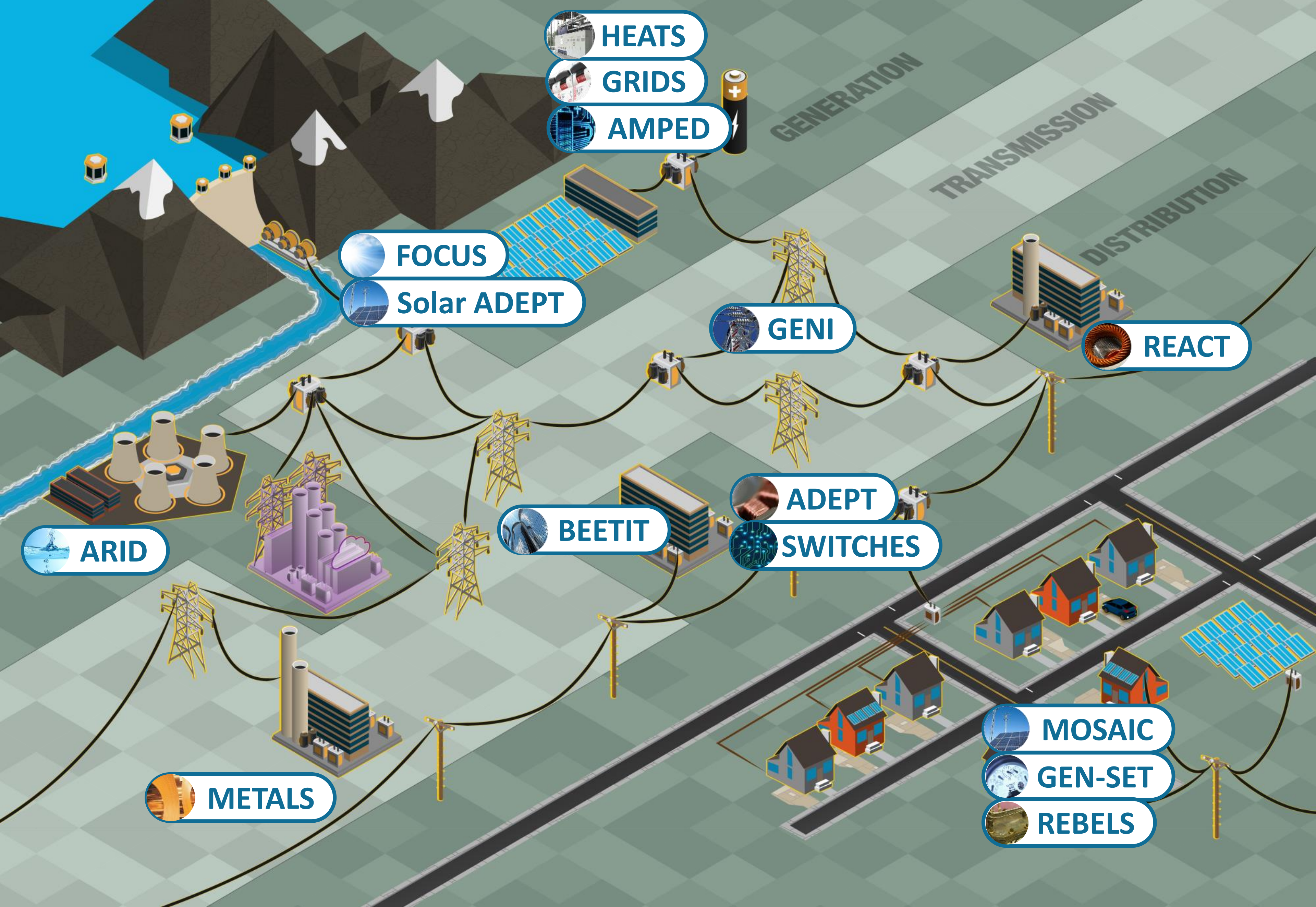
CHANGING WHAT'S POSSIBLE

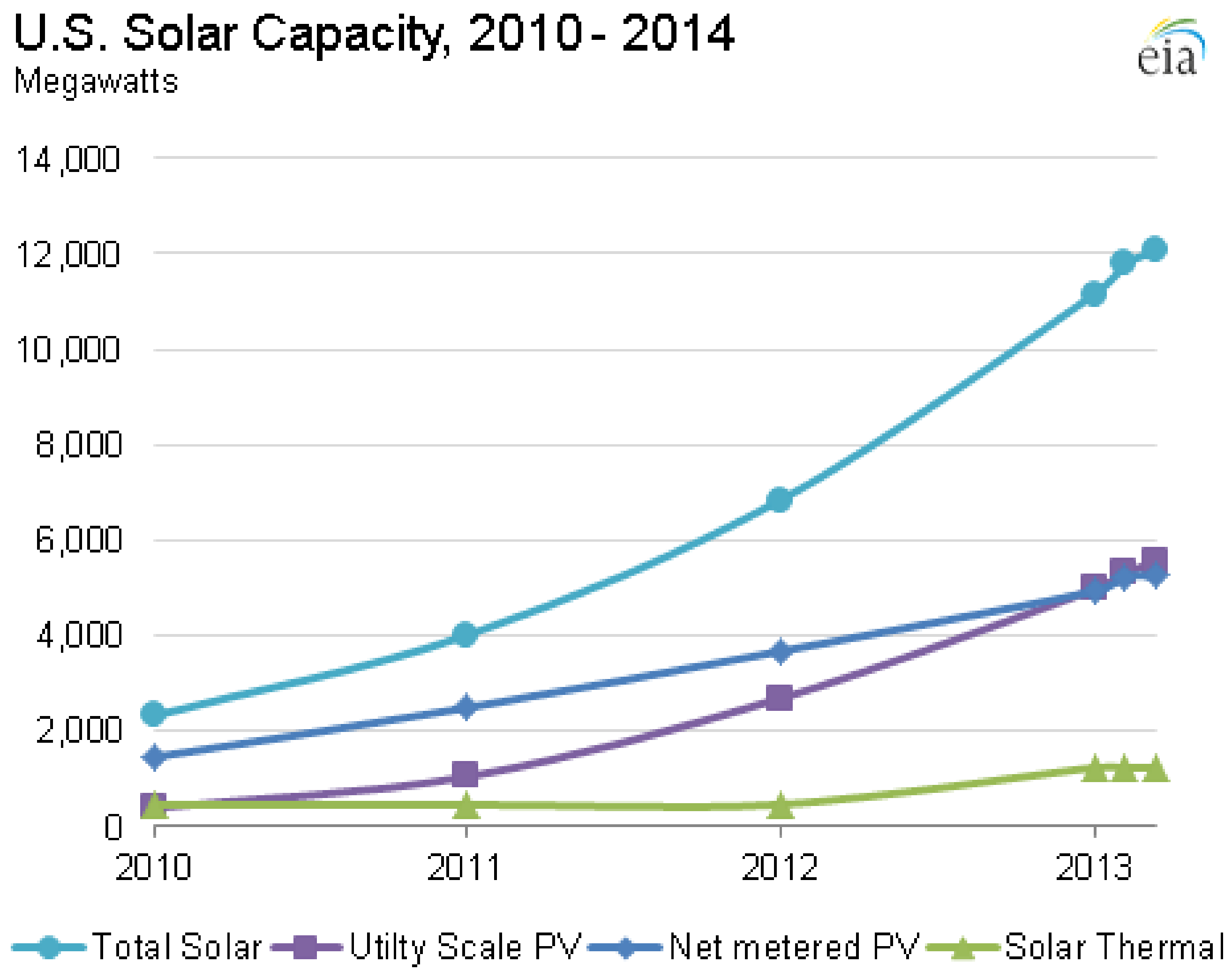
Focused Programs (2009-Present)



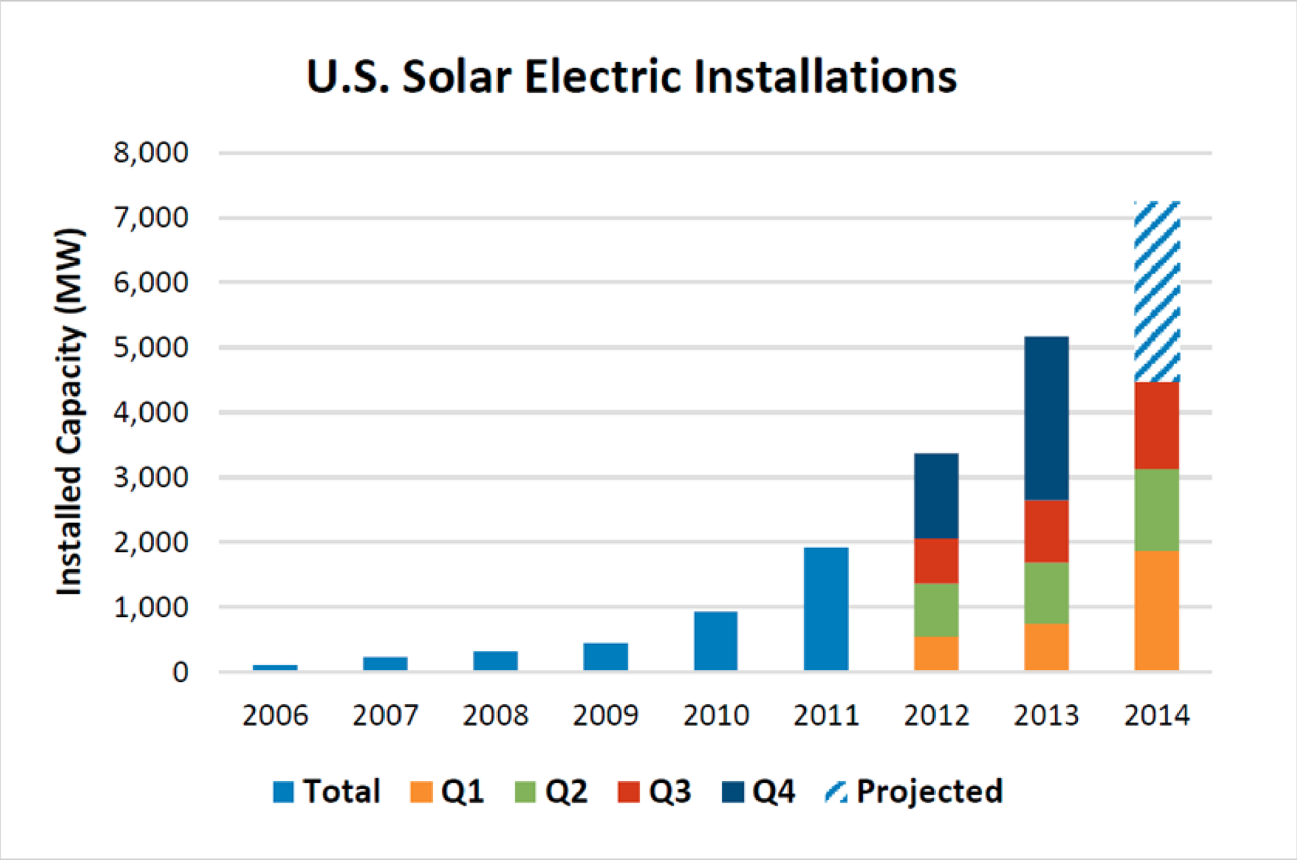
ARPA-E & Electric Power



U.S. Installed Solar Capacity



Solar Installations



GTM RESEARCH
SEIA Solar Energy Industries Association

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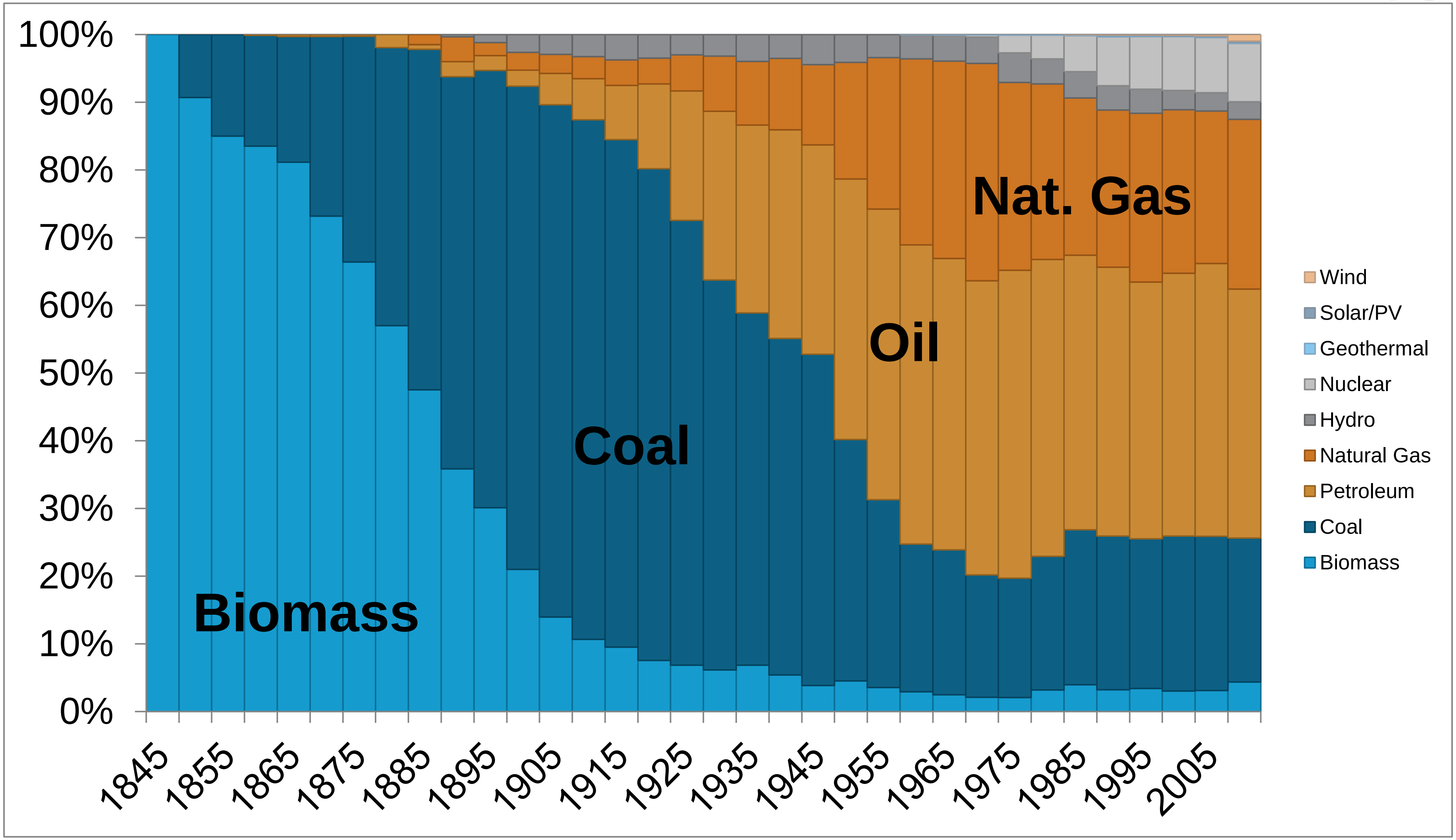
U.S. Primary Energy Consumption



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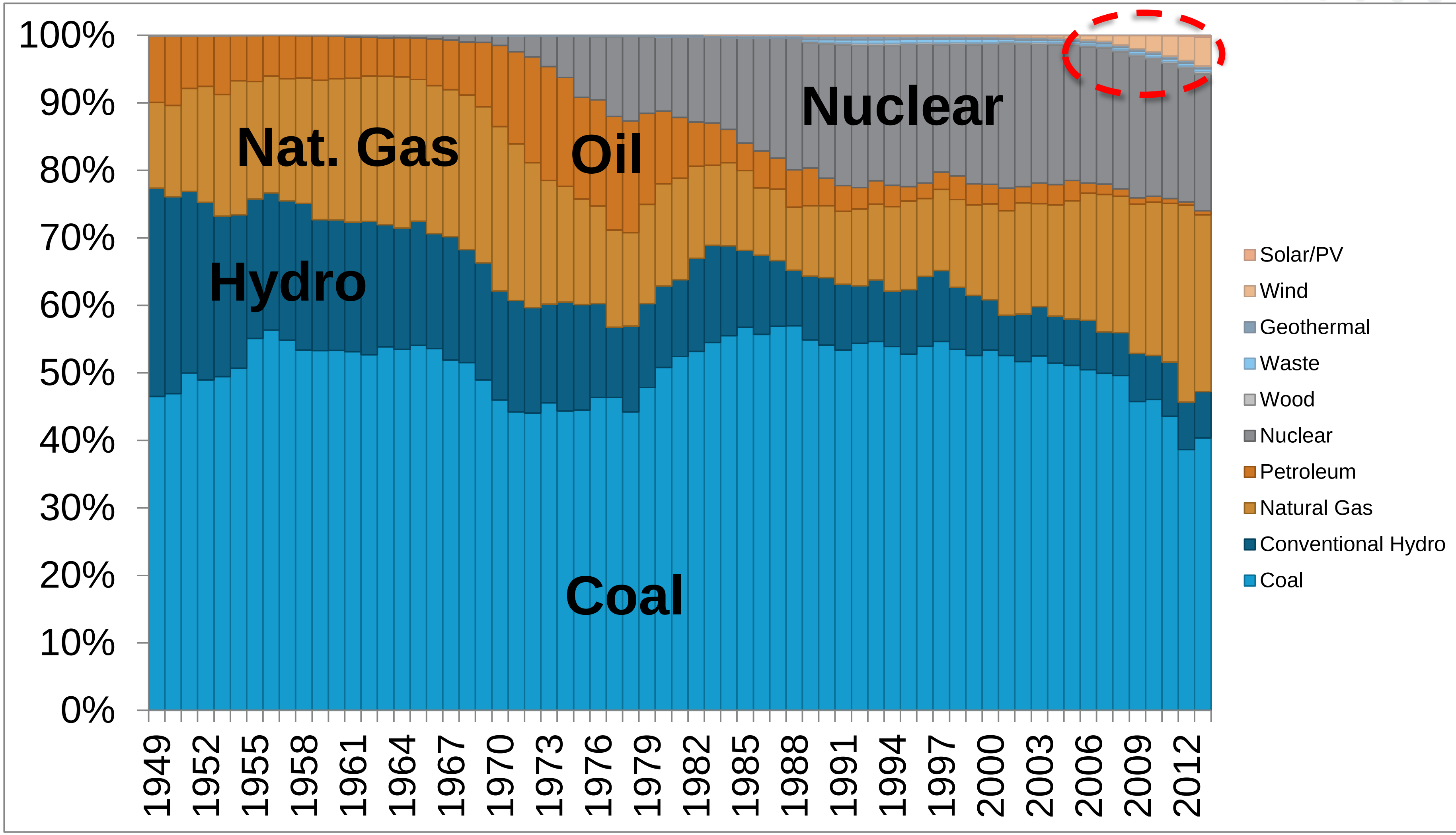
Source: EIA

U.S. Electricity Net Generation



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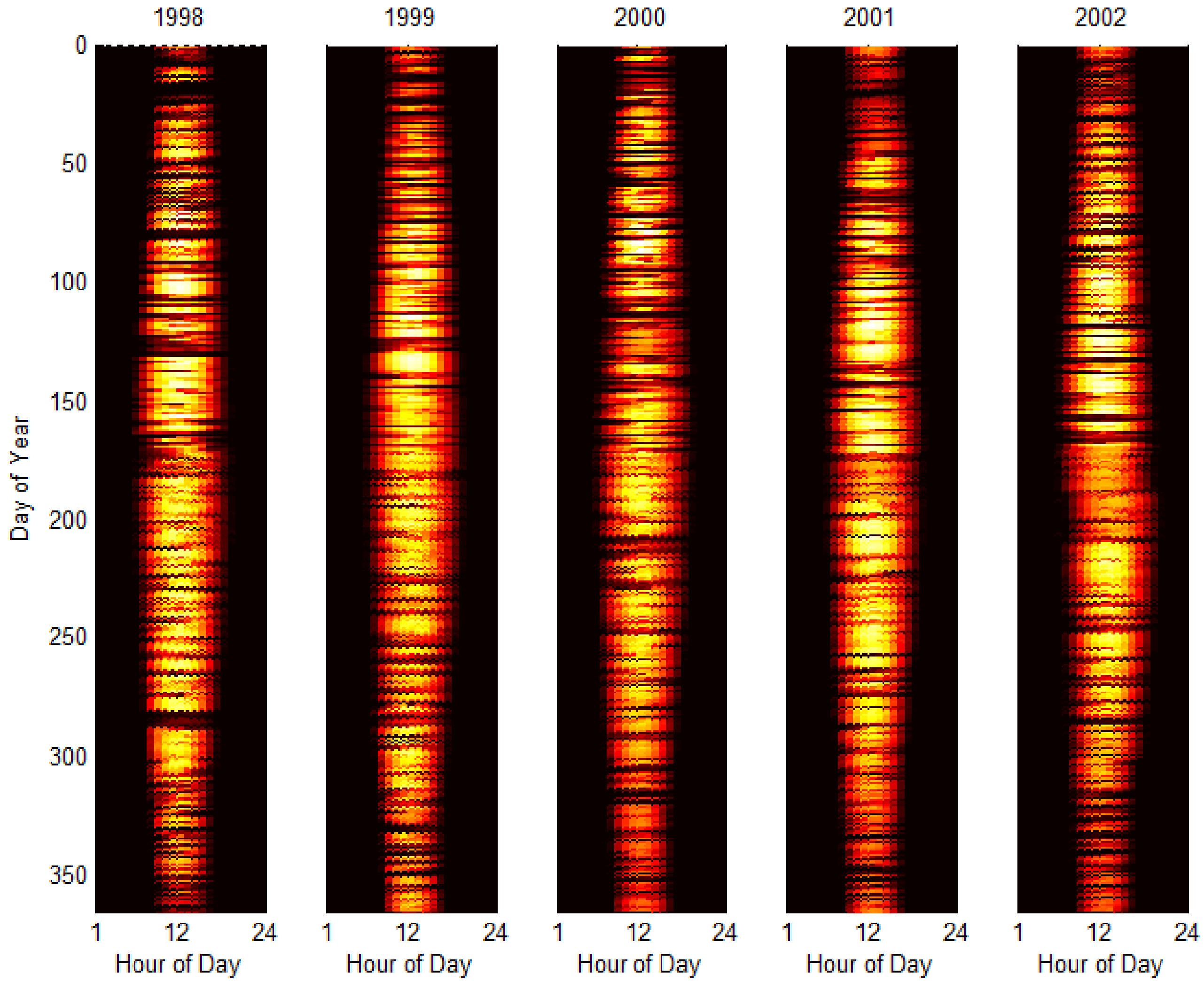
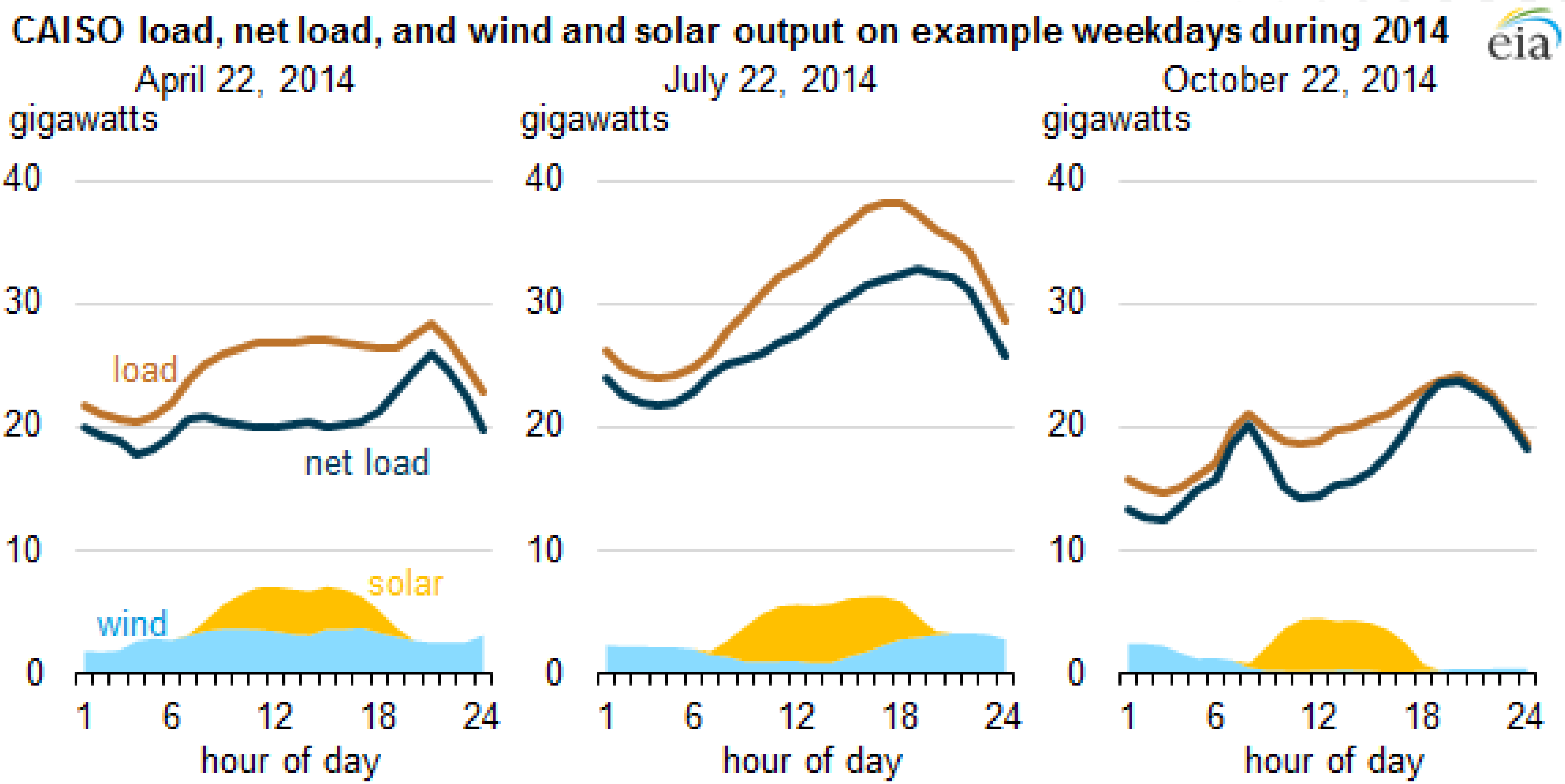
Source: EIA

Variability & Uncertainty

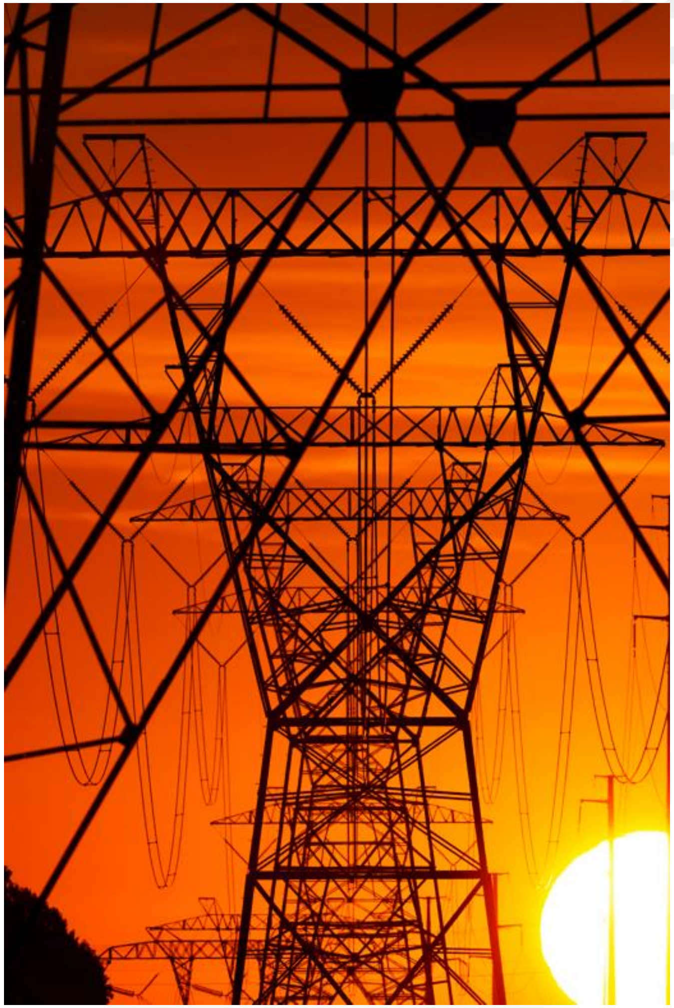


Variability & Uncertainty



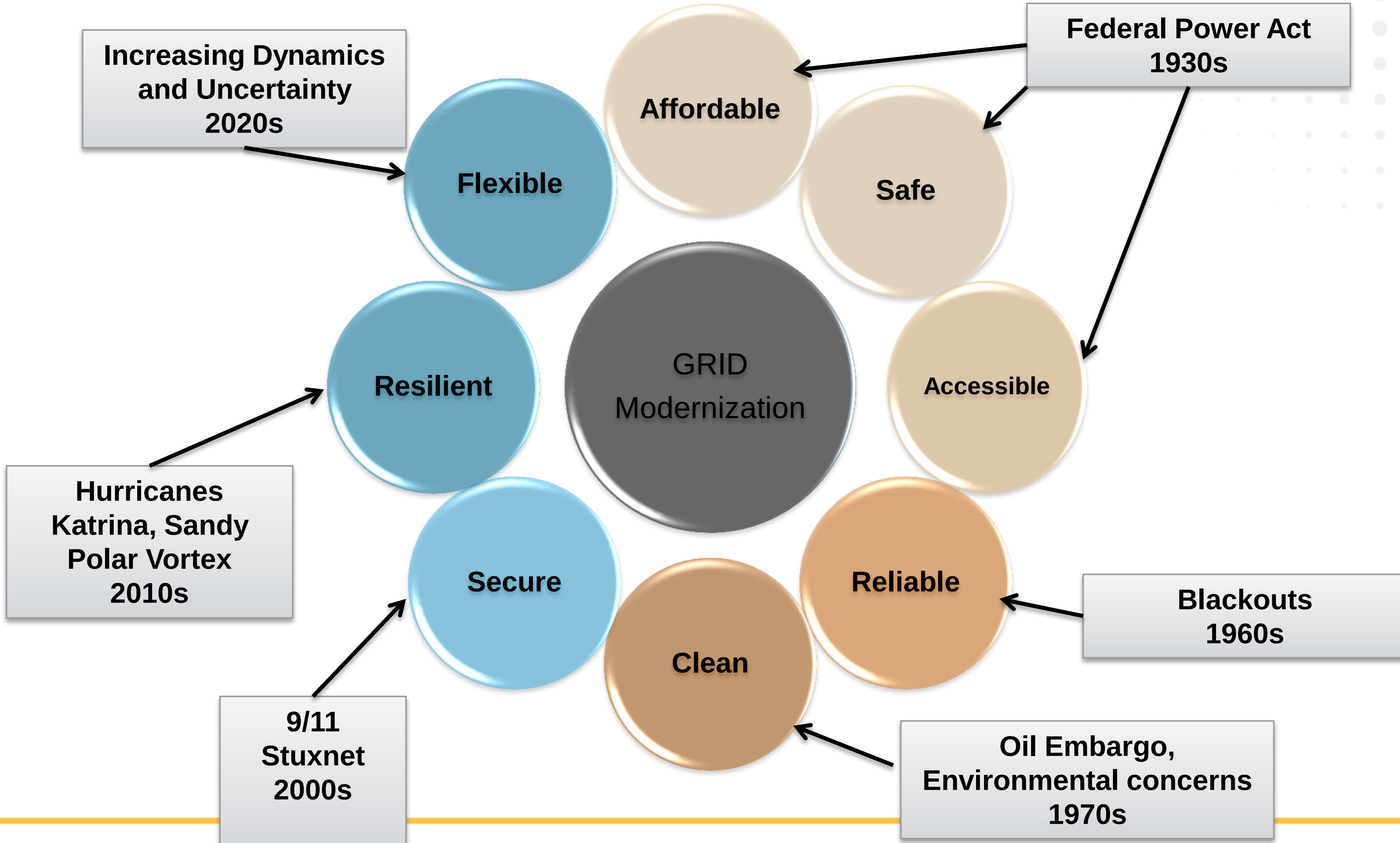
Emerging Power System Challenges

- Increasing wind and solar generation
- Decentralization of generation
- Aging infrastructure
- Changing demand profiles
- Increasing natural gas generation



- **All of these challenges require greater power system flexibility.**

Evolution of Grid Requirements



Source: DOE Grid Tech Team

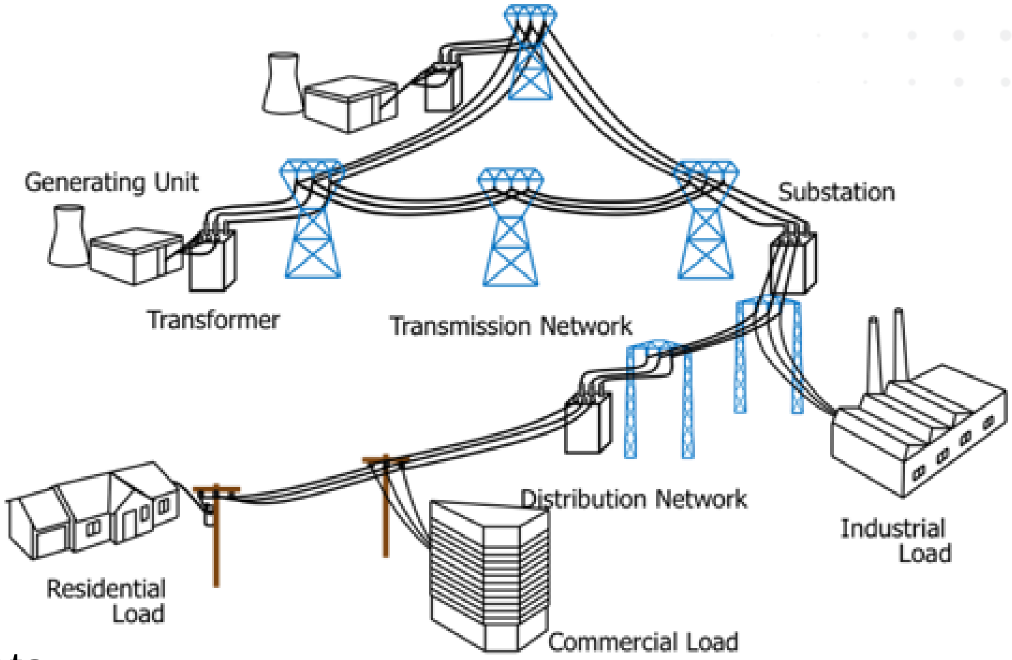
New Potential Sources of Network Flexibility

- **Advances in power electronics, computational technologies, and mathematics offer new opportunities for optimizing grid power flows.**

<u>*Power Flow Controllers*</u>
- AC Power Flow Controllers
- High Voltage DC Systems

<u>*Transmission Topology Optimization*</u>
- Optimal line switching
- Corrective switching actions

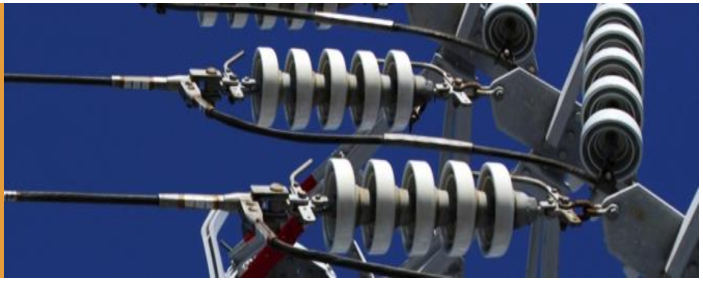
<u>*Energy Storage Optimization*</u>
- Scheduling energy flows
- Coordination of diverse storage assets



<u>*Responsive Demands*</u>
- Scheduling large loads (eg. industrial loads)
- Mobilize large numbers of small assets

GENI Program

Green Electricity Network Integration



Goals

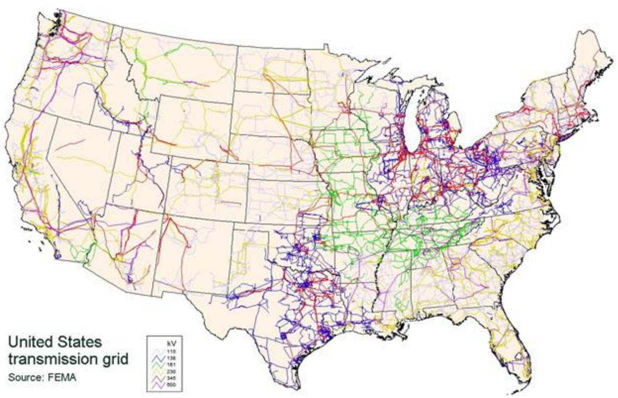
- Enable 40% variable generation penetration
- > 10x reduction in power flow control hardware (target < $0.04/W)
- > 4x reduction in HVDC terminal/line cost relative to state-of-the-art

Kickoff Year	2011
Projects	15
Total Investment	$39 Million
Program Director	Tim Heidel (Rajeev Ram)

Project Categories

- Power Flow Controllers
  - Power flow controllers for meshed AC grids.
  - Multi-terminal HVDC network technologies.
- Grid Control Architectures
  - Optimization of power grid operation; incorporation of uncertainty into operations; distributed control and increasing customer optimization.

Power flow control



Power flow control: the ability to change the way that power flows through the grid by actuating line switching hardware or by controlling high voltage devices connected in series or in shunt with transmission lines.

- Power flow control includes the ability to:
  - control the impedance on a major transmission line
  - inject a controlled voltage in series with a line
  - provide reactive voltage support for long lines so that they can be loaded to their thermal limits
  - switch line circuit breakers to redirect power to other lines.

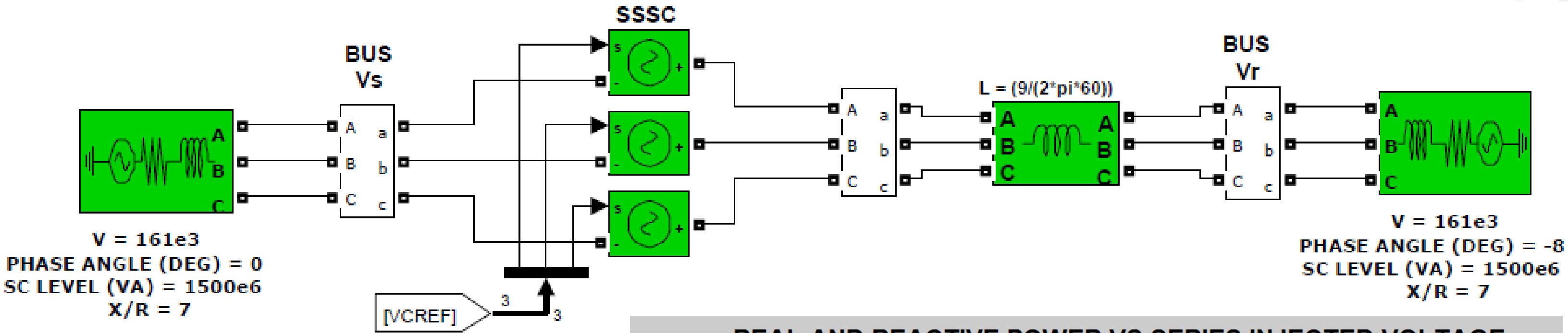
Map: U.S. Department of Energy Office of Science and Technology osti.gov

Power Flow Control - Historical Background

- System operators historically had the ability to influence power flows by
  - Generation dispatch and curtailment
  - Tap changing on voltage phase angle regulating transformers
  - Switching transmission lines and interties
  - Switching capacitor banks

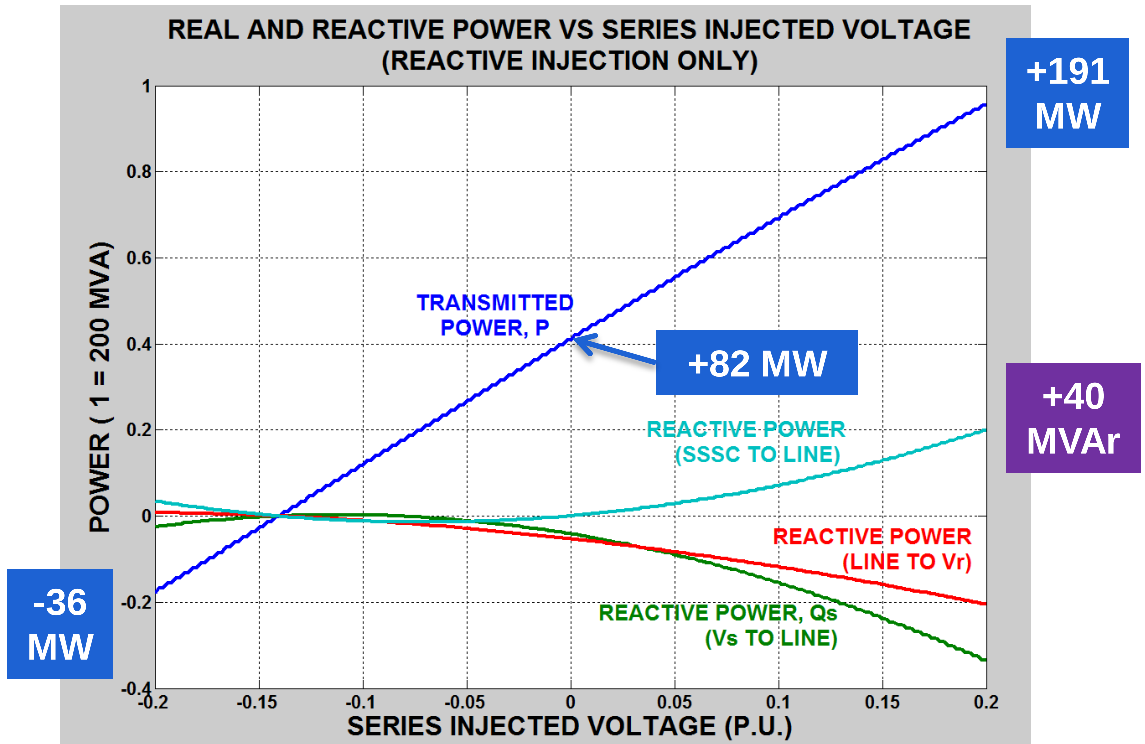
- Various power electronics-based controllers have been proposed that can offer more granular and faster time scale power flow control:
  - Thyristor-controlled Static Var Compensators (SVC)
  - Thyristor-controlled phase angle regulators and voltage regulators
  - Thyristor-controlled series capacitors (TCSC)
  - Line-Commutated Converter (LCC) HVDC
  - Static Synchronous Compensator (STATCOM)
  - Voltage Source Converter (VSC) HVDC
  - Static Synchronous Series Compensator (SSSC)

REACTIVE SERIES POWER INJECTION CAN INCREASE, REDUCE, OR REVERSE TRANSMITTED REAL POWER



161 kV TRANSMISSION LINE EXAMPLE:

- ***P = 82 MW WITH NO INJECTED VOLTAGE***
- ***P = +191 MW WITH +0.2 P.U. VOLTAGE INJECTION (SSSC OUTPUT = +40 MVAr)***
- ***P = -36 MW WITH -0.2 P.U. VOLTAGE INJECTION (SSSC OUTPUT = +7 MVAr)***



Source: Colin Schauder, unpublished.

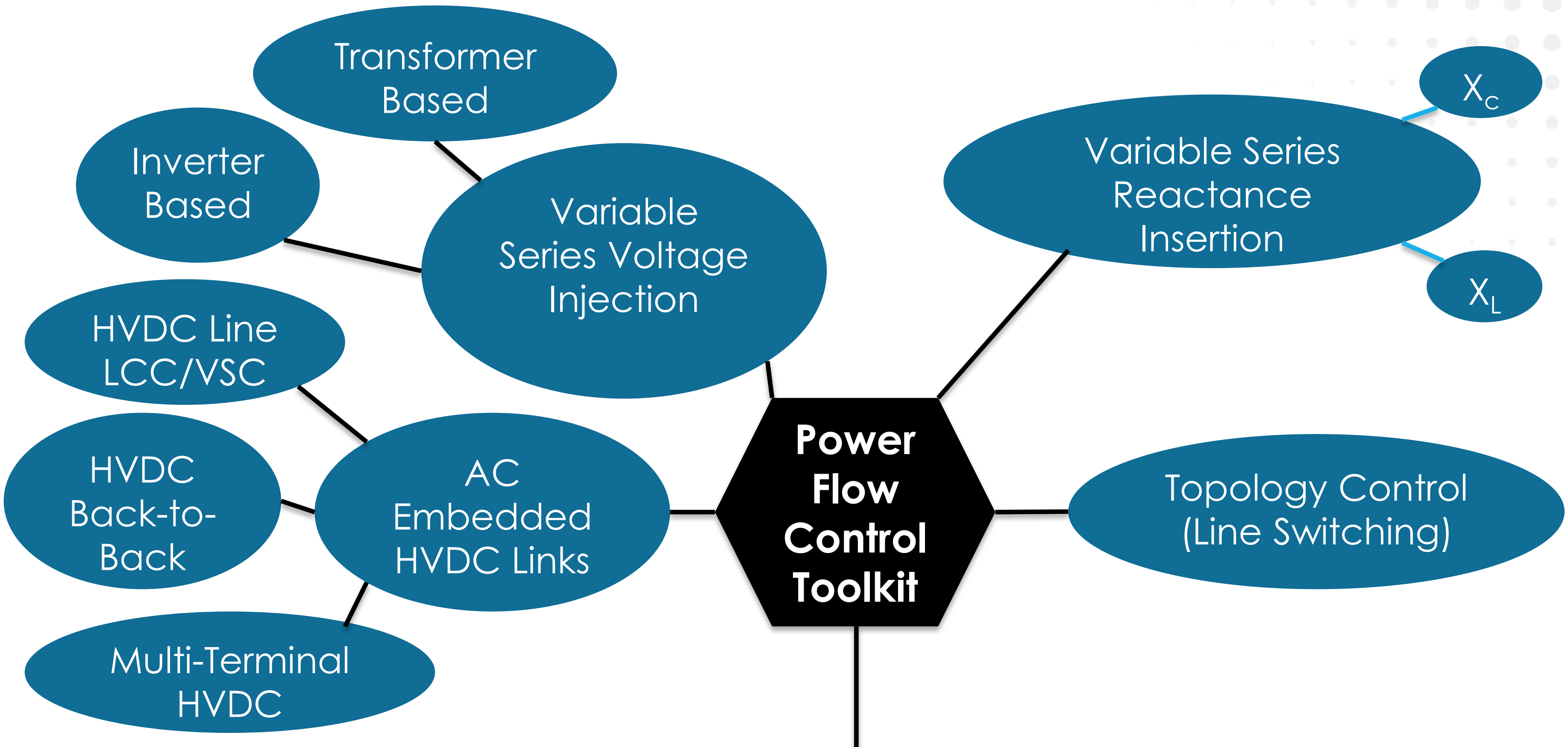
Power Flow Control White Space

- Historically, power flow control devices have typically been manually dispatched to correct local problems.
- High costs and reliability problems are often cited against the widespread installation and use of power flow control devices.
- ***New hardware*** innovations that can substantially reduce the cost of power flow control devices are needed
  - Fractionally rated converters (limited power device ratings).
  - Modular designs (increases manufacturability).
  - Series connected equipment with fail normal designs (gradual degradation).
- ***New software*** advances that exploit new developments in optimization and computational technologies are needed to enable the real time coordinated, optimized dispatch of many power flow control devices.

Program Targets (Power Flow Controllers)

Primary Technical Targets (from Original Funding Opportunity Announcement)
TEST BED: Minimum of 3 controllers/terminals connected on a small-scale mesh with a minimum of 5 nodes. Terminals configured for operation at > 10kV. (Individual elements tested at relevant transmission level voltages (>100kV).)
RESILIENCY: Protocol for testing the resiliency and stability of the interconnected controllers.
BI-DIRECTIONAL FLOW CONTROL: Software controls with simulated latency used to demonstrate full bi-directional control of real and reactive power flows.
HIGH EFFICIENCY: Conversion efficiency of controllers/terminals must be > 99%.
COMMERCIAL FEASIBILITY: A cost-benefit analysis for a single controlled link using the proposed technology on the transmission grid is required.
AC MESH CONTROLLERS: >10x reductions in cost (target cost < $0.04/W).
MULTI-TERMINAL HVDC CONTROLLERS: >4x reductions in terminal and line cost.

Power Flow Controllers



Fast, Reliable, Ubiquitous Communications

Advances in Power Electronics (Components and Circuits)*

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* ARPA-E's ADEPT, Solar ADEPT, and SWITCHES programs are funding some of these advances.

GENI Portfolio

Power Flow Control Hardware

Varentec
Compact Dynamic Phase Angle Regulator

Oak Ridge National Laboratory
Magnetic Amplifier

Michigan State University
Transformerless UPFC

Power flow control for the Grid
SWG
Distributed Series Reactor

HVDC Hardware

GE
HVDC EPR Cable

General Atomics
DC Breaker

GE
HVDC Multi-terminal Network Converters

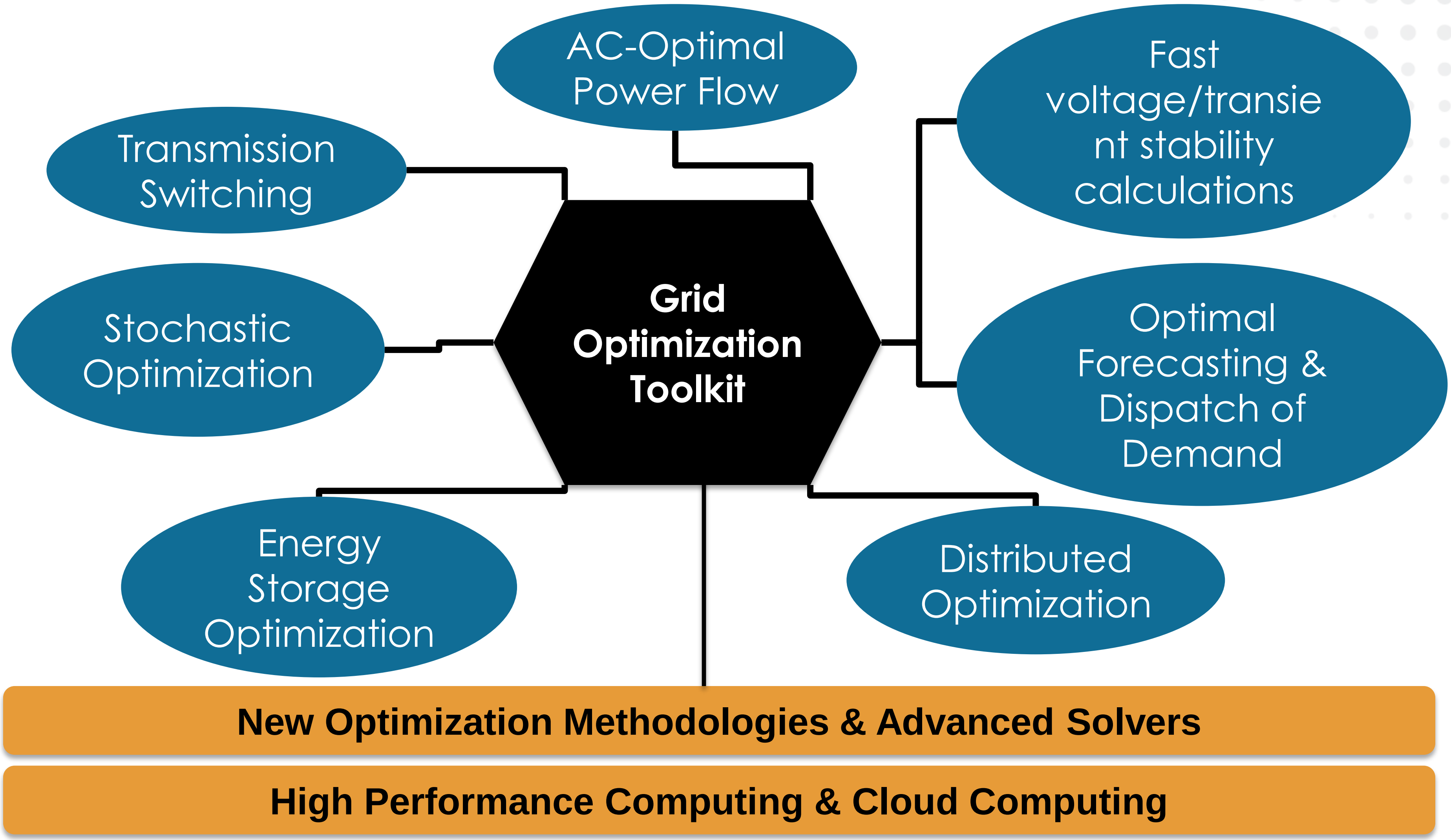
Grid Control Architectures Whitespace

- Increasing variability and uncertainty
- Need to coordinate far larger numbers of energy resources
- Need new algorithms that can ensure robust, reliable control of the electricity grid despite:
  - The limits of state estimation (finite numbers of sensors and comms. limits);
  - Incomplete and imperfect information flow (due to latency of communications);
  - Constrained computational resources for dynamic decision support (power flow optimization is mathematically (NP) hard);
  - Inherent uncertainties in market mediated transactions; and
  - Physical constraints to control (cost, performance, and reliability of power electronics).

Program Targets (Grid Control Architectures)

Primary Technical Targets (from Original Funding Opportunity Announcement)
SCALABILITY: Capable of managing large dynamical systems (>10,000 nodes)
VALIDATION: Real-world datasets supplied by transmission operators or utilities.
FEASIBILITY: Consideration of sensing, communications, computational, and actuation (ramp and dispatch) challenges for implementation in “real-time” markets.
FAILSAFE: Designs where a safe, “dumb” operation occurs in the event of local or wide- area failure or attack.

Grid Control (Optimization) Architectures



GENI Portfolio

Power Flow Control Hardware

varentec
Compact Dynamic Phase Angle Regulator

Oak Ridge National Laboratory
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Michigan State University
Transformerless UPFC

Power flow control for the Grid
SWG
Distributed Series Reactor

HVDC Hardware

GE
HVDC EPR Cable

General Atomics
DC Breaker

GE
HVDC Multi-terminal Network Converters

Topology Control (Line Switching)

Boston University
Economic Optimization

TEES Texas A&M Engineering Experiment Station
Contingency Management

Cloud Computing & Big Data

Cornell University
Resilient Cloud / Data Replication

AutoGrid
Demand Response

Power System Optimization

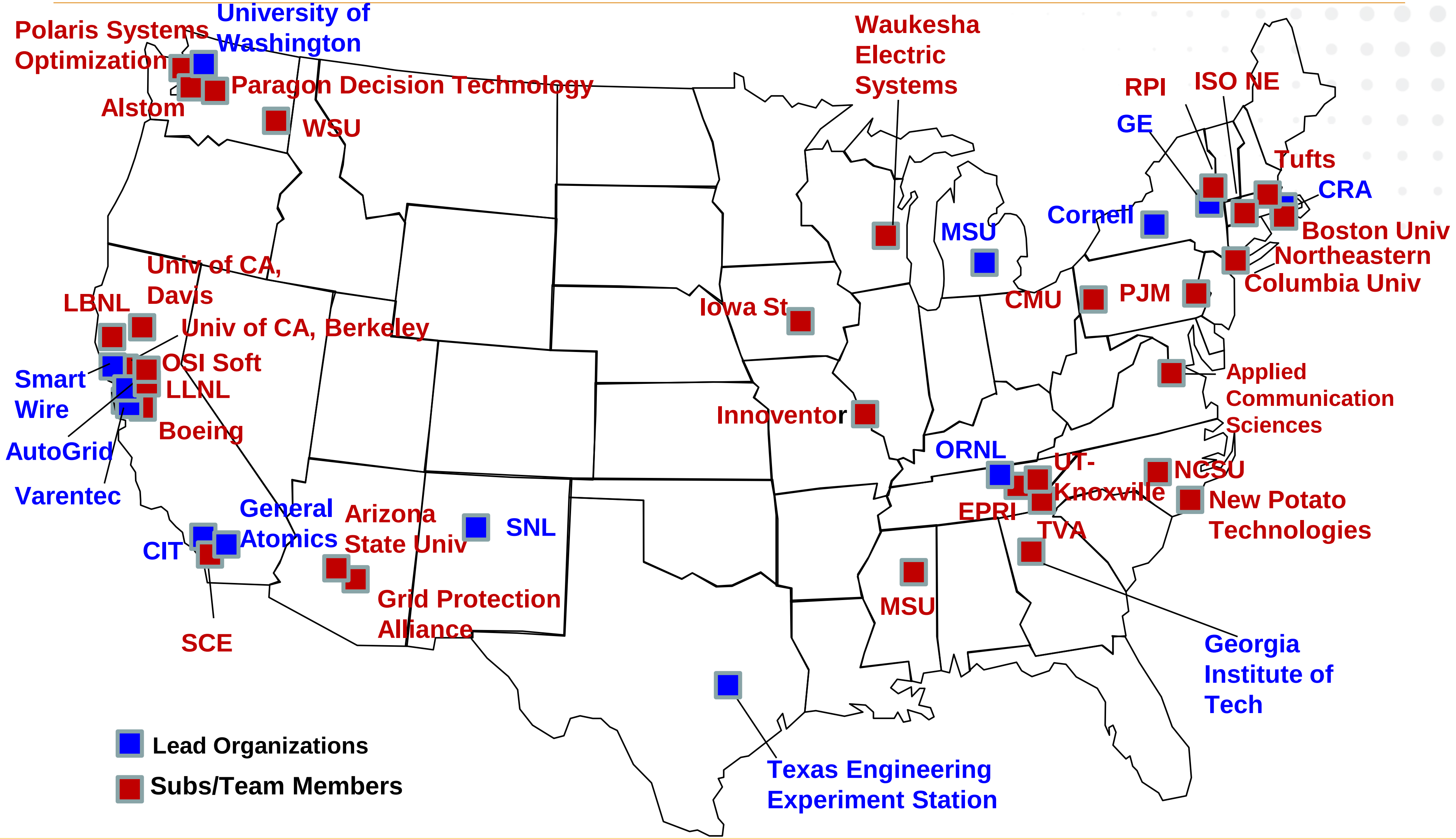
California Institute of Technology 1891
AC-OPF

Sandia National Laboratories
Stochastic Unit Commitment

University of Washington
Energy Storage Optimization

Georgia Tech
Distributed Grid Optimization (Prosumers)

GENI Program Participants



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OPEN 2012

OPEN FUNDING SOLICITATIONS FOR ALL ENERGY TECHNOLOGY AREAS

Mission

- OPEN funding solicitations provide opportunities for high-potential projects that address the full range of energy-related technologies and concepts.

OPEN FOA 2012	66 Projects
	$130 Million
	11 Technology Areas

GENI Related Projects

- University of Illinois Urbana-Champaign
  - "Cyber-Physical Modeling and Analysis for a Smart and Resilient Grid"
- Pacific Northwest National Laboratory
  - "Non-Wire Methods for Transmission Congestion Management through Predictive Simulation and Optimization"
- University of California Berkeley
  - "Micro-Synchrophasors for Distribution Systems"

Agenda: Wednesday Morning

8:00	**ARPA-E**	**Welcome and Introductions**
8:15	**ARPA-E**	**GENI Overview and Program Accomplishments**
		Grid Optimization & Control
9:15	Georgia Institute of Technology	Prosumer-Based Distributed Autonomous Cyber-Physical Architecture for Ultra-reliable Green Electricity
9:35	Sandia National Laboratories	Improved Power System Operations Using Advanced Stochastic Optimization
9:55	University of Washington	Energy Positioning: Control and Economics
10:15		**BREAK**
10:45	California Institute of Technology	Scalable Real-time Decentralized Volt/VAR Control
11:05	University of California-Berkeley	Micro-Synchrophasors for Distribution Systems
11:25	Discussion	Moderator: Yonghong Chen
12:00		**LUNCH**

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Agenda: Wednesday Afternoon

		Transmission Topology Optimization
13:00	Texas Engineering Experiment Station	Robust Adaptive Topology Control (RATC)
13:20	Boston University	Transmission Topology Control for Integration of Renewable Generation
13:40	Pacific Northwest National Laboratory	Non-Wire Methods for Transmission Congestion Management through Predictive Simulation and Optimization
14:00	Discussion	Moderator: Terry Oliver
14:30		**BREAK**
		Computational Advances for Enhancing Reliability and Facilitating Renewables
15:00	Cornell University	GridControl: A Software Platform to Support the Smart Grid
15:20	University of Illinois	Cyber-Physical Modeling and Analysis for a Smart and Resilient Grid
15:40	Discussion	Moderator: Robin Podmore
16:30		**POSTER SESSION**

Agenda: Thursday Morning

8:00	**ARPA-E**	**Welcome and Recap**
		Power Flow Control Hardware
8:15	Varentec, inc.	Compact Dynamic Phase Angle Regulators for Transmission Power Routing
8:35	Michigan State University	Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission
8:55	Oak Ridge National Laboratory	Magnetic Amplifier for Power Flow Control
9:15	Smart Wire Grid	Distributed Power Flow Control using Smart Wires for Energy Routing
9:35		**BREAK**
9:50	GE Global Research	Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics / Nanoclay Reinforced Ethylene-Propylene-Rubber fof Low Cost HVDC Cabling
10:15	Discussion	Moderator: Jason Handley
10:45	**Discussion**	**Performer Perspectives on Technology to Market Efforts**
11:45		**LUNCH**

Agenda: Thursday Afternoon

		Power System Simulations of Power Flow Controllers / Benefit Studies
12:30	Energy Exemplar (SWG)	Distributed Power Flow Control using Smart Wires for Energy Routing
12:45	PowerWorld (SWG)	Distributed Power Flow Control using Smart Wires for Energy Routing
13:00	EDD (SWG)	Distributed Power Flow Control using Smart Wires for Energy Routing
13:15	EPRI (Varentec)	Compact Dynamic Phase Angle Regulators for Transmission Power Routing
13:30	Georgia Institute of Technology (Varentec)	Compact Dynamic Phase Angle Regulators for Transmission Power Routing
13:45	University of Tennessee	Magnetic Amplifier for Power Flow Control
14:00	Michigan State University	Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission
14:15	Discussion	Moderator: Kevin Lynn
14:45	**Discussion**	**Program Director Wrap-up**

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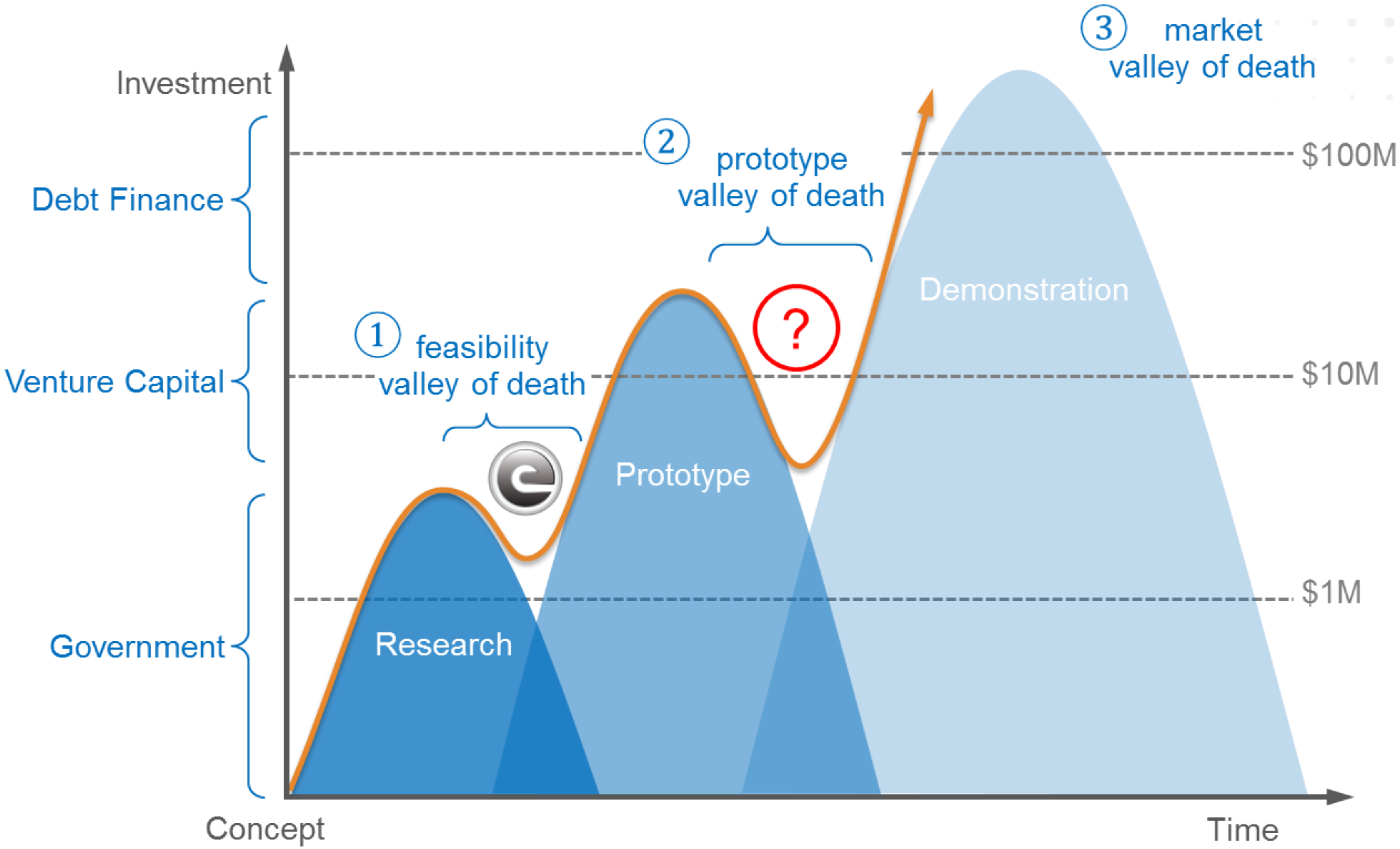
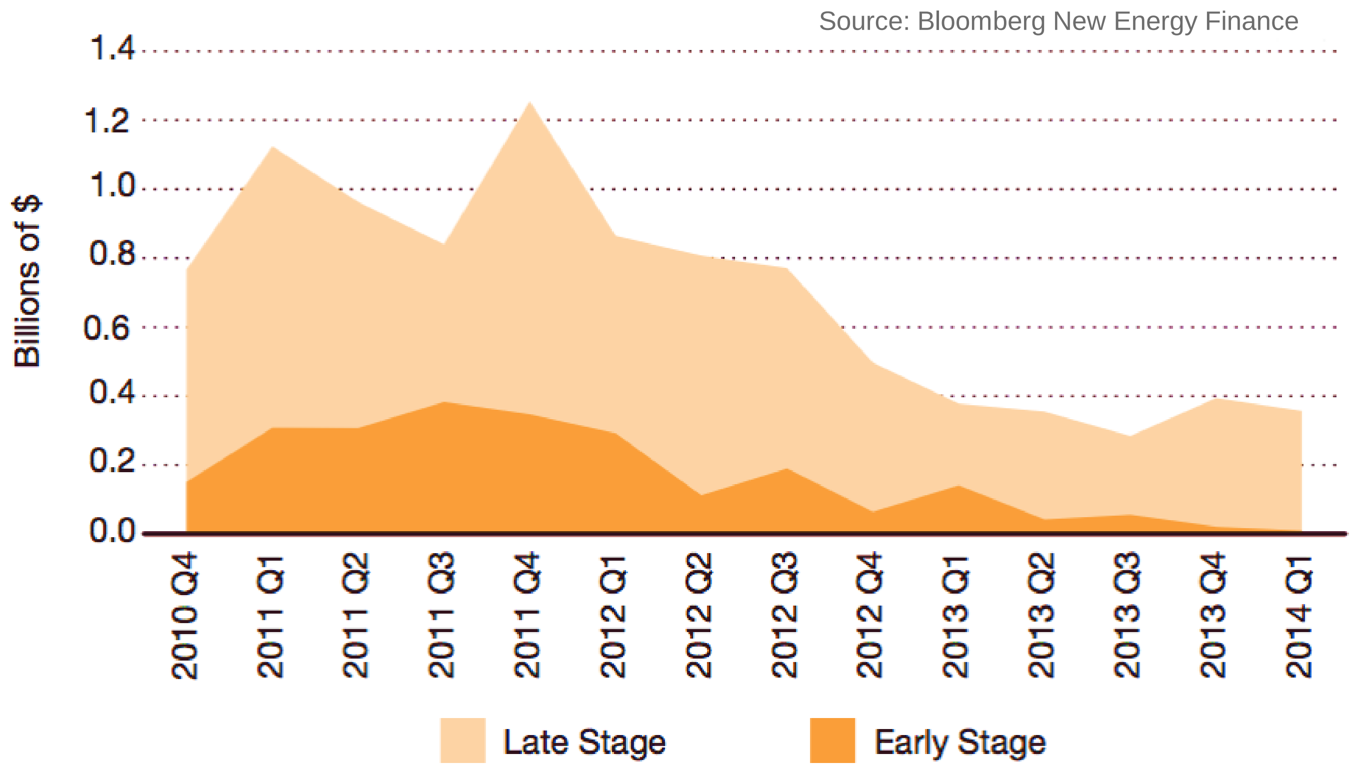
Meeting Objectives

- Discuss the program's accomplishments (especially the final year results).
- Provide critical feedback on approaches and applications.
  - Share perspectives across value chain and industry sectors.
- Strengthen the community.
  - Explore partnership opportunities and potential synergies.
- Plan for post GENI technical challenges
  - What technical challenges will remain?
  - What critical pieces are still missing?

Energy Technology "Valleys of Death"



Declining Cleantech Investment



Who will fund the development of engineered prototypes?

www.arpa-e.energy.gov

Program Directors

ARPA-E is continually recruiting new Program Directors, who serve 3-year terms

ROLES & RESPONSIBILITIES

Program development

- Perform technical deep dive soliciting input from multiple stakeholders in the R&D community
- Present & defend program concept in climate of constructive criticism

Active project management

- Actively manage portfolio projects from merit reviews through project completion
- Extensive “hands-on” work with awardees

Thought leadership

- Represent ARPA-E as a thought leader in the program area

ATTRIBUTES

- R&D experience; intellectual integrity, flexibility, and courage; technical breadth; commitment to energy; communication skills; leadership; and team management
- ***A passion to change our energy future***

If you are interested please contact me or any ARPA-E program director

Fellows

ARPA-E is also recruiting Fellows, who serve 2-year terms

ROLES & RESPONSIBILITIES

Identification of high-impact energy technologies

- Perform technical and economic analyses to identify high-impact energy technologies.
- Publish original research papers and reviews.

Program director support

- Help develop future programs through technical analysis, discussions, and workshops.
- Assist with management of current projects, including site visits.

Organizational support

- Review proposals for funding opportunities.
- Contribute to the strategic direction and vision of the agency.

ATTRIBUTES

- Ph.D. in science or engineering; strong analytical and communication skills; ability to work independently and across disciplines; leadership.
- ***A passion to change our energy future***

If you or one of your students are interested please contact me, an ARPA-E program director, or a Fellow

Evaluation Forms

GENI Panel Discussion Survey

Panel Topic: ____

1. How helpful were the project presentations in this session? How could they have been improved?

2. How helpful was the discussion? How could th…

3. How excite… …ssed in this session? Why?

…ortant potential barriers to the adoption of these technologies were not s…ntly discussed during this session?

5. What topics/questions should the panel have discussed that it did not? What questions do you wish we had spent more time discussing?

Feedback on Every Topic/ Panel Session

GENI%Annual%Review%Survey%%

1. Please!evaluate!this!session!on!the!following!criteria,!and!tell!us!why!you!have! given!this!score:!

Overall!quality!of!presentations!and!discussion:!

!	1!–!Poor!	2!	3!	4!	5!–! Excellent!
Topology!Control!	!	!	!	!	!
AC!Power!Routing!	!	!	!	!	
What!Matters!on!the! Grid:!Risk!&!Money!	!	!	!		
HVDC!Power!Routing!	!				!
Cloud!Infrastructure! and!Big!Data!Sets!			!	!	!

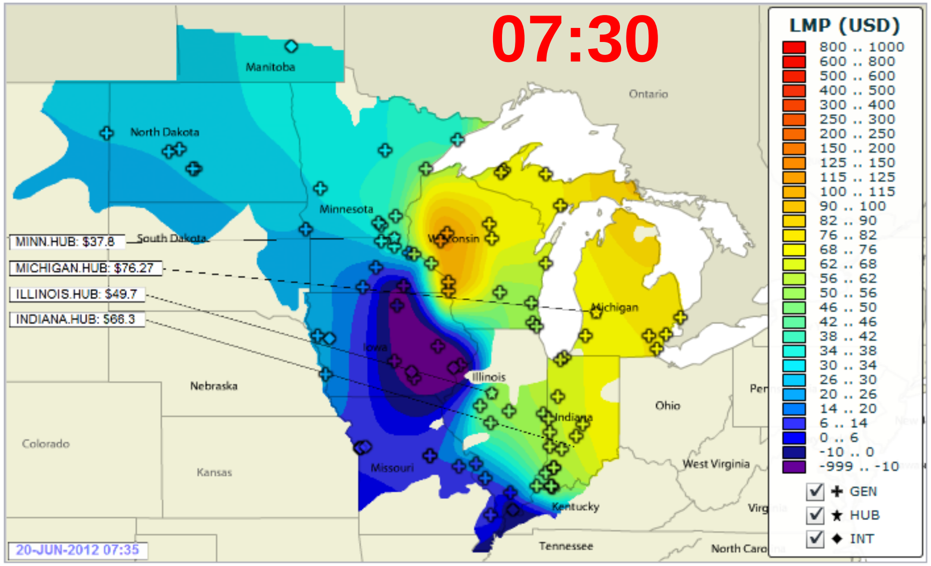
Comment…

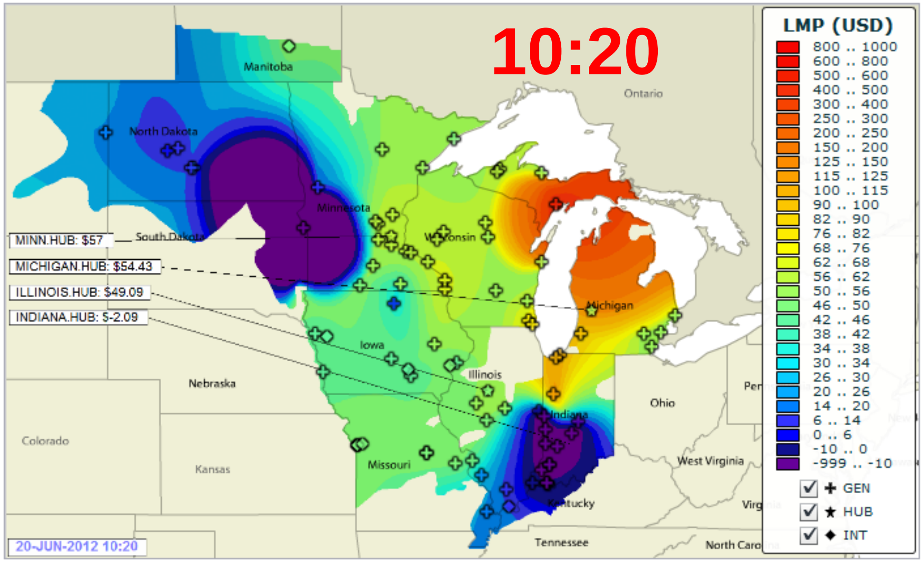
Overall Feedback on the Event

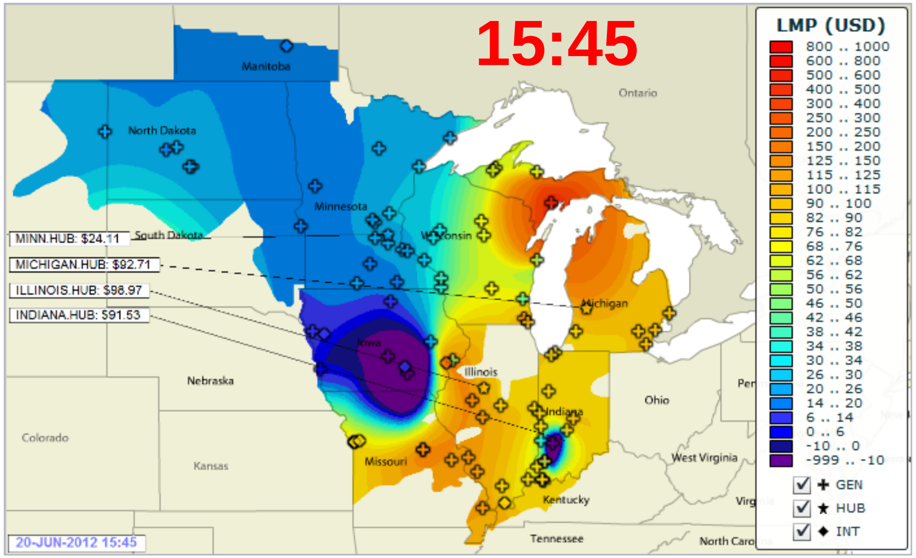
www.arpa-e.energy.gov

Optimal Transmission Network: When?

Midwest ISO real time LMPs for June 20th, 2012







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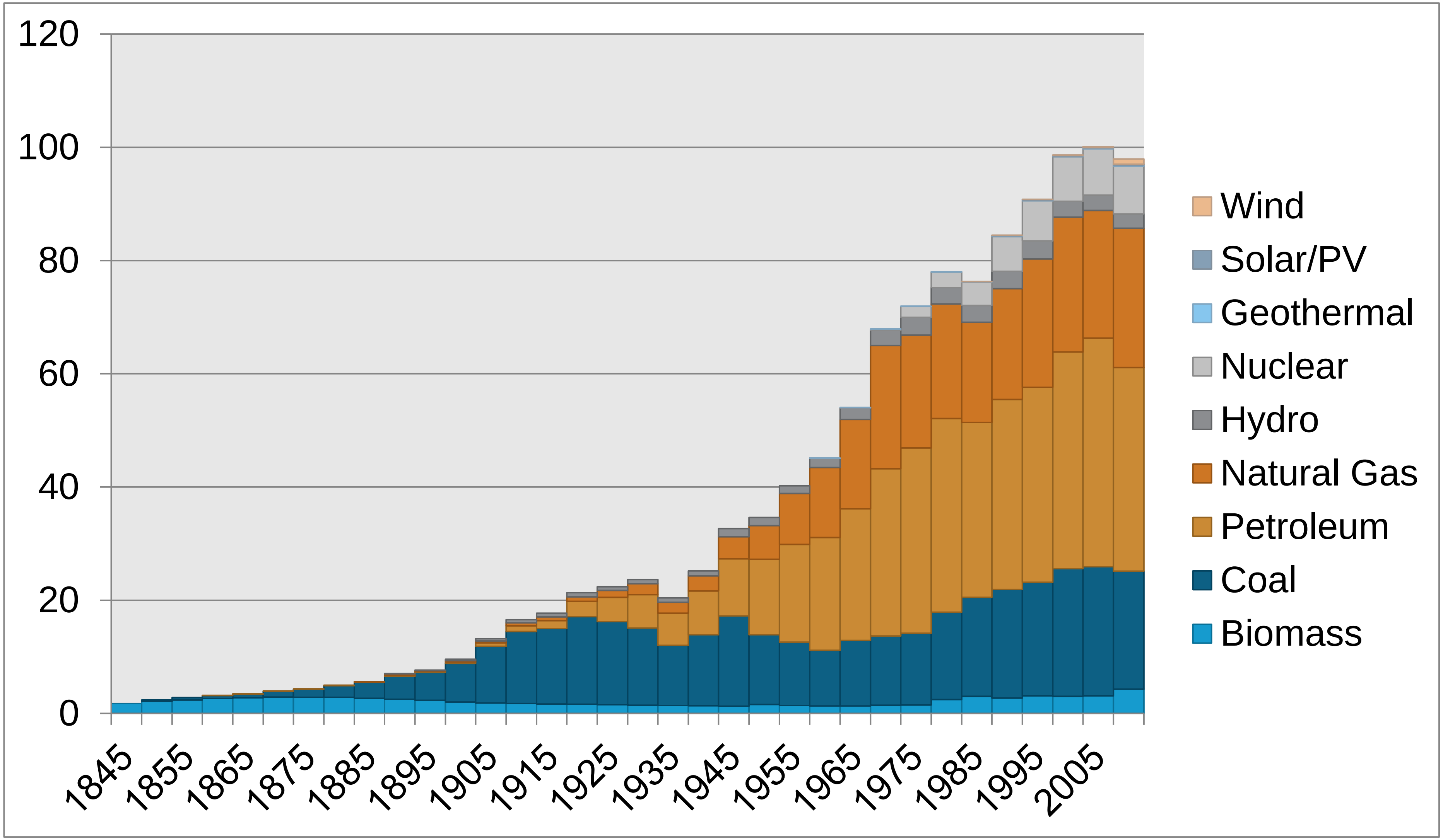
U.S. Primary Energy Consumption



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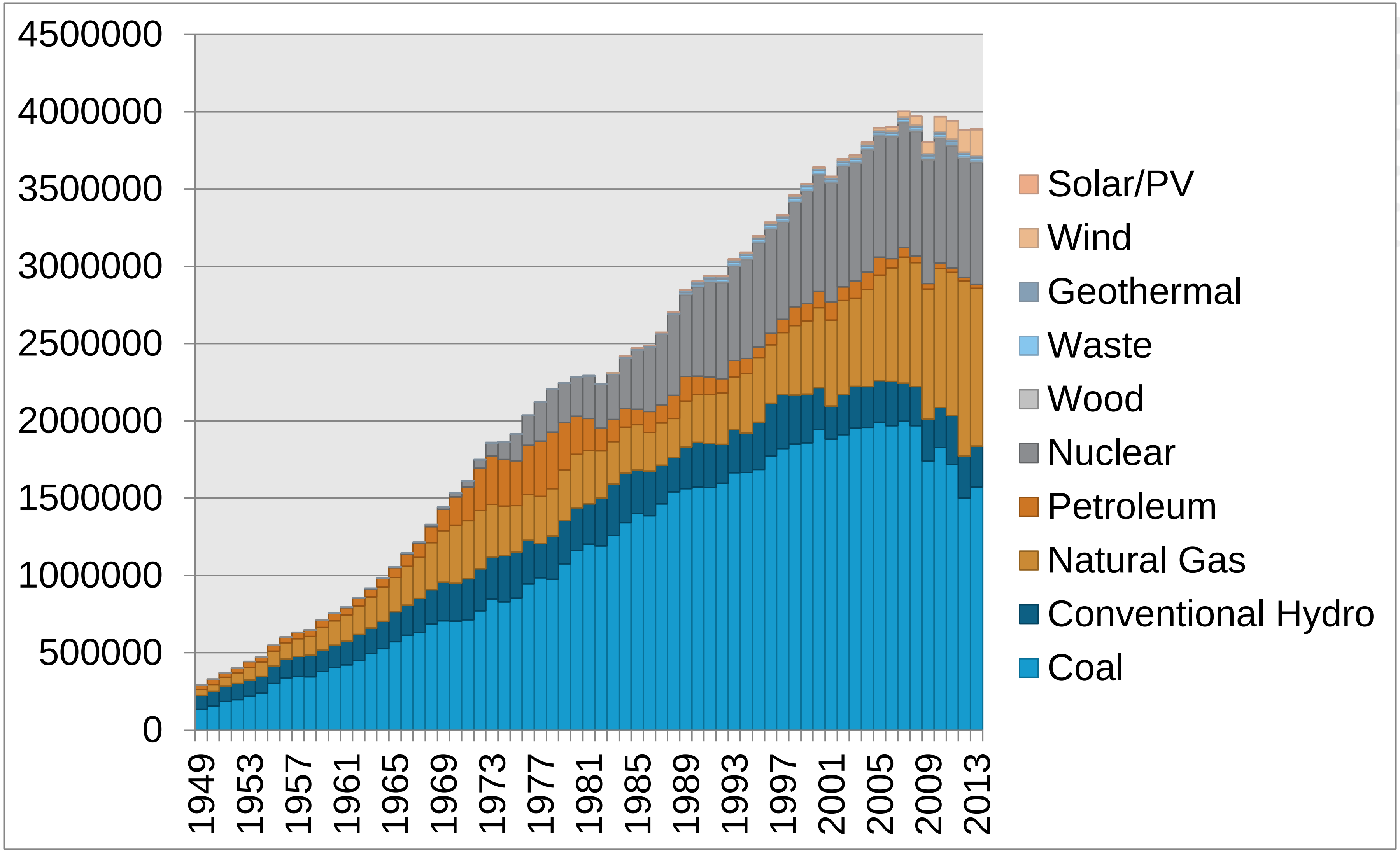
Electricity Consumption



Major Power Electronics-based Power Flow Controllers	
Thyristor-controlled Static Var Compensators (SVC)	Available since the 1970's. Provide voltage support allowing increased line loading.
Thyristor-controlled phase angle regulators and voltage regulators	Available for a long time. Transformer-based. Not as widely used as their mechanically switched counterparts.
Thyristor-controlled series capacitors (TCSC)	Available in different forms for decades. Widely used for compensation of long transmission lines.
Line-Commutated Converter (LCC) HVDC	Available for many decades. Best suited for bulk power transmission over great distances.
Static Synchronous Compensator (STATCOM)	Similar functionality to SVCs but utilizing voltage source converters.
Voltage Source Converter (VSC) HVDC	Increasingly used for cable transmission. Most powerful flow control capability. BTB VSC HVDC can solve many AC transmission flow problems, but at relatively high cost (two converters each rated for full transmitted power plus reactive generation).
Static Synchronous Series Compensator (SSSC)	Demonstrated in 3 UPFC installations starting in the 1990's. Fractional series voltage injection can control large swings in transmitted power. No known stand-alone SSSC installations (or UPFC's) built for transmission systems after the initial demonstrations.